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a. REPORT	b. ABSTRACT	c. THIS PAGE			David Hu
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RPPR Final Report
as of 25-Feb-2019

Agency Code:

Proposal Number: 63207EG **Agreement Number: W911NF-13-1-0347**
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Begin Performance Period: 12-Aug-2013 **End Performance Period:** 30-Sep-2018
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STEM Degrees: 2 **STEM Participants:** 2

Major Goals: The overall goal is to develop a program to discover adaptability principles of fire ants, Solenopsis invicta, under diverse conditions. This work will build on the PI's previous work on fire ants to discover principles of shelter construction, adaptation to vibration, internal dynamics of aggregations, and responses to external forces. The program will be composed of four research thrusts, each of which can operate separately but will ultimately interact: instrumentation development, biological studies, physical modeling and material properties characterization. These will advance biomechanics, robotics and active materials research.

We have also been investigating the behavior of aggregations of another active matter system, black soldier fly larvae. These larvae are small soft insects on the same scale as fire ants and that also spend time in aggregations. Unlike fire ants, they do not create links between each other. However, they do generate coherent flows. They thus a simpler model for studying collective behavior, and makes it easier to separate the effects of biology and physics in behavior of aggregations.

The principles found in this study will help guide in design of modular robots as well as the algorithms to guide them in building in dynamic environments.

Accomplishments: • Swarm dynamics of black soldier fly larvae
We have been studying the eating rates of these fly larvae. We find that the eating rates of larvae are limited by the surface area of the food they are consuming. Each larva eats for 44% of the time it is around food, for 5±8 minutes at a time. Although their mouths are tiny, they eat a lot – twice their body mass per day. Their mouths consist of brushes that the larvae use to scoop food into their mouths, which we visualize with scanning electron microscopy and high speed videos. We use particle image velocimetry to analyze the motion of larvae around food from the top and bottom of a container.

• Elephant trunk matter transport
We have observed various matter transport of elephant trunks including small granular media, fluid transport, and heavy weightlifting. We found that an elephant trunk can lift upwards of 65kg through wrapping around a barbell. The elephant trunk experienced stress in many different forms, however the bending stress from the weight lifting was the largest of these. We observed that the trunk also forms joints to squeeze smaller objects together. In order to grab very small food, the elephant creates a joint on their trunk 0.1 m away from the contact point. We compare this work to that of soft robotic manipulators and see that the elephant trunk has larger strength and flexibility as it compares to that of current soft robotics.

Training Opportunities: Nothing to Report

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Results Dissemination: Media
- 13 April 2018. Science Friday. “The Very Hungry Maggot” by Luke Groskin and Lauren J. Young.
- 14 February 2017. Gizmodo. “Send This Video of Maggots Eating a Heart-Shaped Donut to Your Love” Ryan F. Mandelbaum
- 27 October 2015. Newsweek. “Video: ants act like both liquids and solids” Douglas Main
- 26 October 2015. Gizmodo. “Everything in the future could be made of ants” Esther Inglis-Arkell
- 26 October 2015. Popular Mechanics. “A teeming mass of ants acts like a liquid and a solid” Jay Bennett
- 28 October 2015. Physics World. “Swarming fire ants show solid and liquid properties” Tim Wogan
- 27 October 2015. Futurity. “Teeming ants act like both a liquid and a solid” Jason Maderer
- 26 October 2015. Phys.org . “Ants: both solid-like and liquid-like”
- 26 October 2015. ScienceDaily. “How ants and ketchup are alike: both solid-like and liquid-like”

Media
- 13 April 2018. Science Friday. “The Very Hungry Maggot” by Luke Groskin and Lauren J. Young.
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- 26 October 2015. ScienceDaily. “How ants and ketchup are alike: both solid-like and liquid-like”

Presentations
- Shishkov, O., Hu, M., Johnson, C., Hu, D. L Feeding Fly Larvae Form a Fountain. Poster presented at the Society for Integrative and Comparative Biology, Tampa, FL. January 4, 2019 (Invited).
- Shishkov, O., Hu, M., Hu, D. L. Fly Larvae Feed by Forming a Flowing Fountain. APS DFD 2018 Annual Meeting, Atlanta, GA, November 19, 2018.
- Shishkov, O., Fuentes-Cabrera, M., Hu, D. L. Active mixing in aggregations of black soldier fly larvae. Poster presented at the 2018 CNMS User Meeting, Oak Ridge National Laboratory, August 13, 2018.
- Shishkov, O., Hu, D. L Competition of feeding fly larvae causes active mixing. iPoLS 2018 Annual Meeting, Rice University, June 24, 2018.
- Shishkov, O., Hu, D. L Collective motion of fly larvae during feeding. 11th Annual Meeting on Soft Materials, Emory University, May 23, 2018.
- Shishkov, O., Hu, D. L Collective forces of black soldier fly larvae. American Physical Society March Meeting, Los Angeles, CA , March 8, 2018.
- Shishkov, O., Hu, D. L. Fly larvae mix to increase eating rates. 2017 AIChE Annual Meeting, Minneapolis, MN., November 1, 2017 (Invited).
- Shishkov, O., Hu, D. L. Fly larvae mix to increase eating rates. 2017 Active Materials Project Summer School. Georgetown University, Washington, DC, June 11, 2017.
- Shishkov, O., Hu, D. L. Active mixing of black soldier fly larvae during feeding. The 10th Southeast Meeting on Soft Materials. Atlanta, GA, Friday, May 12, 2017.
- Shishkov, O., Hu, D. L. Self-mixing of fly larvae during feeding. The Geilo School 2017: Physics Inspired by Living Matter. March 20-30, 2017.
- Shishkov, O., Johnson, C., Hu, D. L. Self-mixing of fly larvae during feeding. American Physical Society March Meeting, New Orleans, LA, March 13-17, 2017
- Shishkov, O., Johnson, C., Zhang, B., Hu, D. L., Self-mixing of fly larvae during feeding. Divizing of Fluid Dynamics annual meeting, Portland, Oregon, November 20-22, 2016.
- Shishkov, O., Johnson, C., Hu, D. L. Active mixing increases feeding rate of black soldier fly larvae. Active and Smart Matter: A New Frontier for Science and Engineering, Syracuse, NY, June 20-23, 2016
- Shishkov, O, Hu, D. L. Active mixing of black soldier fly larvae. Soft Matter & Lunch Event, Georgia Institute of Technology, April 2016
- Tennenbaum, Michael, David Hu, and Alberto Fernandez-Nieves. "Dynamics of fire ant aggregations." APS March Meeting, 2016.

- Invited talk. Ants, eyelashes and the Ig Nobel Prize in Physics. 69th Annual Meeting of APS Division of Fluid Dynamics, Portland, Oregon, November 2016.
- Invited Speaker for International Congress of Entomology (ICE) to be held in Orlando, Florida, Sept. 25-30, 2016. Host: Marianne Alleyne
- Renaissance Weekend by the Renaissance Institute. Ant rafts. Banff. June 30 – July 4.
- Invited speaker for Adhesion Society annual meeting in San Antonio, TX. Fire Ants as Living Adhesives. Feb 21-24, 2016. Host: Chelsea Davis
- Invited speaker for AAAS Annual meeting. Washington, D.C. Annals of Improbable Research. Feb 13, 2016. Host: Marc Abrahams
- Mini-symposium on Emerging collective patterns in dynamic swarms. SIAM Conference on Applications of Dynamical Systems. Fire ants build, morph, and repair to survive floods Hosts: Klimka Szwaykowska and Luis Mier-y-Teran. May 17-21, 2015 in Snowbird, Utah.
- Schulz A., Wu J, Hu, D.L. Elephant Power Lifters. Oral presentation at Southeastern Regional Society of Integrative and Comparative Biology 2018 Meeting – Clemson, SC, November 10, 2018
- Schulz A., Wu J, Hu, D.L. How an Elephant Trunk Lifts and Wraps. Oral presentation at American Physical Society Division of Fluid Dynamics National Conference – Atlanta, GA, November 19, 2018
- Schulz A., Wu J, Hu, D.L. Elephants wrap their trunks around objects to better distribute forces. Oral presentation at Society of Integrative and Comparative Biology 2019 National Meeting - Tampa Bay, FL, January 5, 2019

Honors and Awards: •Profile in New York Times. “The Mysteries of Animal Movement”. November 5, 2018.
- Winner of 2019 Steven Vogel Award for Best Student Poster within the Division of Comparative Biomechanics for "Feeding Fly Larvae Form a Fountain” at the Society for Integrative and Comparative Biology, January 5, 2019.
- One of two winners of outstanding poster award (from 16 posters) for "Self-mixing of fly larvae during feeding" at The Geilo School 2017: Physics Inspired by Living Matter. March 24, 2017.
- 2015 Best Documentary Segment, New York Festivals International TV & Film Awards. “Ant Engineers,” produced by Kelly Peckham at Discovery Channel, filmed in David Hu’s lab. https://youtu.be/5GnSf0lgafQ
- Ig Nobel Prize in Physics. Awarded at Harvard University. September 17, 2015

Protocol Activity Status:

Technology Transfer:
- Shishkov, O. and Hu, D.L. U.S. Patent Application No. 62/627,355 “Aerating Bed for Black Soldier Fly Larvae” Filed: February 7, 2018

PARTICIPANTS:

Participant Type: Graduate Student (research assistant)
Participant: Jia Ning Wu
Person Months Worked: 12.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Olga Shishkov
Person Months Worked: 12.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)

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Person Months Worked: 12.00 **Funding Support:**
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Article Title: Fire ants actively control spacing and orientation within self-assemblages
Authors:
Keywords: Granular, Entanglement, cooperative, emergent, packing
Abstract: To overcome obstacles and survive harsh environments, fire ants link their bodies together to form self-assemblages such as rafts, bridges and bivouacs. Such structures are examples of self-assembling and self-healing materials, as ants can quickly create and break links with one another in response to changes in their environment. Because ants are opaque, the arrangement of the ants within these three-dimensional networks was previously unknown. In this experimental study, we applied micro-scale computed tomography, or micro-CT, to visualize the connectivity, arrangement and orientation of ants within an assemblage. We identified active and geometric mechanisms that ants use to obtain favorable packing properties with respect to well-studied packing of inert objects such as cylinders. Ants use their legs to push against their neighbors, doubling their spacing relative to random packing of cylinders. These legs also permit active control of their orientation, an ability ants use to arr
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Nothing to upload